SEAS UNDER ICE: STABILITY OF WATER OCEANS WHITIN ICY WORLDS

Javier Ruiz[(1)], Alberto G. Fairén[(2)]

[(1)]Departamento de Geoámica, Universidad Complutense de Madrid, 28040 Madrid, Spain, Email: jaruiz@geo.ucm.es
[(2)]Seminar on Planetary Sciences, Universidad Complutense de Madrid

ABSTRACT

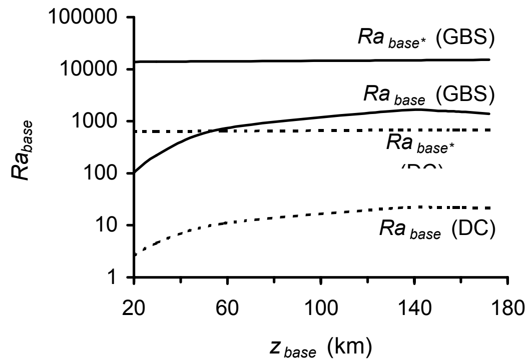
The possible existence of internal oceans in some icy bodies of the outer Solar System has been recently suggested in a joint of observations that cover a wide range of evidences: induced magnetic fields in Europa, Ganymede and Callisto [e.g., ref. 1], induced by Jupiter's field in an electricity-conducting layer near the surface, likely salty water; hydrated minerals on the surface of Europa and Ganymede [3,4], which suggest the presence of water on the surface in the past, with probably an inner source; geological evidences of a mobile layer a few kilometers beneath the surface of Europa [5]; or a recent resurfacing in Triton suggested by the craterization's density and distribution [6]. But the nature of the different proposed liquid layers could be very different, although the own existence of inner oceans could be a common phenomena.

1. THE ICE VISCOSITY

Traditionally, it was thought that an ice shell floating over an ocean in a large ice satellite would be unstable against solid-state convection [e.g., ref. 7]. The efficiency of this process in removing heat from the interior is so that, once initiated, must drive to the freezing of any liquid water layer in a time no longer than some hundreds of millions of years. This is consequence of assuming ice viscosity as Newtonian (stress-independent). But laboratory experiments [8,9] show that iced water viscosity in planetary conditions is non-Newtonian (stress dependent). An analysis for the case of Callisto [10], taking into account non-Newtonian viscosity, showed that its outer ice shell should be stable against convection. This implies that the energy provided by radioactive isotopes in the rocky fraction must be enough to let an inner ocean to escape from freezing and survive to date. The argument can be extended to the rest of the icy satellites of the outer Solar System.

Here we have applied the methodology in [10] to Titan, using the satellite characteristics as given in [11]. Deformation mechanisms are indicated as GBS (Grain Boundary Sliding) and DC (Dislocation Creep). Fig. 1 that Rayleigh number in the outer ice shell does not reach a value high enough to initiate convection. So, a water ocean might have survived to date, escaping the deep freezing, at a depth of ~130 km (deduced from of radioactive heat sources power).

Fig.1



If convection is more difficult to initiate than previously though, then the existence of inner oceans within icy worlds could be a very common phenomena.

2. ISOLATING LAYERS ON THE SURFACE

If over the surface of an ice world exists a regolith layer, or if a solid-state greenhouse is working, temperature can be greatly elevated very close to surface [e.g., ref. 12]. This could contribute to maintain inner heat, favouring the existence of an internal ocean. Similarly, an ice layer of low thermal conductivity (e.g., nitrogen) over Triton surface could act as a thermal insulating [6]. This argument can be also applied to Pluto. In this graphic the effect of an insulating layer raising surface effective temperature on the depth to an inner ocean is shown for Triton. It is considered transmission of heat by conduction in the ice layer, and radioactive heating in the rocky satellite fraction as the only energy source.

It can be seen in Fig.2 that if effective surface temperature is close to observed surface temperature (38 K), fusion point of water ice (assumed as 273 K) is reached at depths up to ~330 km, similar to those

Fig. 2

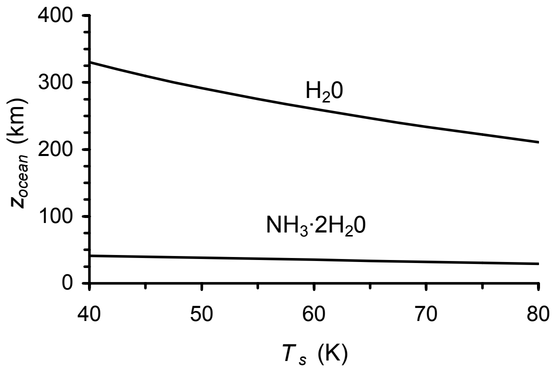
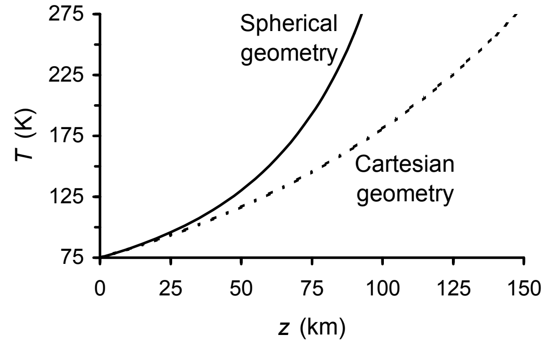


Fig. 3



estimated if all water in Triton is frozen. But a more elevated effective surface temperature allows to reach water fusion point at depths close to ~200 km. This would make possible the existence of a pure water ocean. If ice contains appreciable quantities of ammonia, which lowers its melting point (176 K) and its thermal conductivity, the stability of an ocean seems to be inevitable at depths not greater than ~30-40 km under surface.

3. THE EFFECT OF SPHERICAL GEOMETRY IN SMALL-SIZE ICY BODIES

In previous works about icy worlds the outer ice shell is frequently treated as an horizontal, "flat" layer. But actually, in the case of small-size satellites as Enceladus, the effect of the real spherical geometry can not be forgotten. The young appearance of the surface of Enceladus indicates a thermally evolved body [11], which suggests a differentiated interior, maybe due to an ancient tidal heating epoch. Tidal heating calculations in Enceladus including an inner liquid layer indicate that a high heat flow could be possible [12]. Dotted curve in Fig. 3 shows temperature profile in terms of outer ice layer depth, assuming a cartesian geometry for this layer, temperature-dependent thermal conductivity, and that Enceladus is as tidally heated as suggested. The outer ice shell can be considered heated from below, since warmest ice is more tidally heated [13]. Ice melting temperature is reached at ~140 km depth.

Otherwise, in a spherical shell in thermal conductive equilibrium, vertical heat flow to a distance r from the center is proportional to $r^2 / R^2 = (1 - z / R)^2$, where R is the body radius and z the depth from surface. When this is taken into account in calculations, the temperature profile represented by the solid line is obtained. In this case, fusion temperature is reached at ~90 km depth, which seems to guarantee the existence of a deep water layer. The addition of important quantities of ammonia would lead to a major proximity of this ocean to surface.

4. CONCLUSIONS

The existence of liquid water oceans within icy worlds can be a consequence of the physical properties of water ice, and they would not require the addition of antifreeze substances nor any other special conditions. In fact, it is possible that the inner dynamics of these bodies could really be very different than usually considered. In any case, the incorporation of significant quantities of substances as ammonia or salts seems to make inevitable [14,15] the existence of different and varied seas under ice in the outer Solar System.

REFERENCES

1. Khurana, K.K., *et al.*, *Nature* 395, 777, 1998.
2. Kivelson, M.G., *et al.*, *Icarus* 157, 2002.
3. McCord, T.B., *et al.*, *Science* 280, 1242, 1998.
4. McCord, T.B., *et al.*, *Science* 292, 1523, 2001.
5. Pappalardo, R.T., *et al.*, *JGR* 104, 24,015, 1999.
6. McKinnon, W.B., *et al.*, in *Neptune and Triton* (D.P. Morrison, Ed.) pp. 807-877, Univ. of Ariz. Press, Tucson, 1995.
7. Cassen, P.M., *et al.* , in *Satellites of Jupiter* (D. Morrison, Ed.) pp. 93-128. Univ. of Ariz. Press, Tucson, 1982.
8. Durham, W.B., *et al.*, *JGR* 106, 11,031, 2001.
9. Goldsby, D.L., and Kohlstedt, D.L., *JGR* 106, 11,017, 2001.
10. Ruiz, J., *Nature* 412, 409, 2001
11. Morrison, D., *et al.*, in *Satellites* (J. Burns and M.S. Matthews, Eds.) pp. 764-801, Univ. of Ariz. Press, Tucson, 1986.
12. Ross, M.N., and Schubert, G., *Icarus* 78, 90, 1989.
13. Ojakangas, G.W. and Stevenson, D.J., *Icarus* 81, 220, 1989.
14. Stevenson, D.J., *Eos AGU* Fall Meeting, 2001.
15. Stevenson, D.J., *Eos AGU* Fall Meeting, 2001.